

We must know. We will know.

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Abstract. The after-dinner talk has by now become a tradition of this Conference series on Quark Confinement and the Hadron Spectrum. On this occasion, I have tried to combine a free-style and (hopefully) amusing presentation with deep questions of physics especially connected with the dynamics of strong interaction. To this end some masterpieces of classical music (by Beethoven, Mozart, Dvorak, Stravinsky ...) and pop music (by Bob Dylan, Eric Clapton) were employed to illustrate certain aspects of physics. By no means was this presentation (neither this paper) intended as a comprehensive review of the different topics examined during the Conference, but rather as a call for further thinking on the synergy of different branches of physics and the excitement of foreseen discoveries in a not too distant future.



FIGURE 1. Picture of the great German mathematician David Hilbert. His determination *to know* is a strong inspiration for this article. However, science is currently facing complex issues which concern the essence of the scientific method itself. The dream of a “theory of everything” might become a nightmare for many, when apparently there is no way to find the expected “true solution” from among a huge set of possible vacua!

INTRODUCTION

The defiant statements entitling this paper (“*Wir müssen wissen. Wir werden wissen.*”) pronounced by David Hilbert at the 1930 Annual Meeting of the German Scientists and Physicians, can be viewed by many as too optimistic, conveying a bold belief in the unlimited capacity of the human mind to grasp any law of Nature. In fact, Gödel had announced the first expression of his famous incompleteness theorem just one day before!

In any event, one can truly marvel at the present status of the human understanding of Nature. With the help of sophisticated devices and computers for detection and analysis (which can be interpreted as “magnified” senses and brain), scientists have been able to explore length scales from the extremely tiny to the cosmologically large. This task has been accomplished throughout history by a long (not yet finished), often hard struggle of brave people against ignorance, superstition and fanaticism.

Admittedly, the advancement of science looks now unstoppable, fueled by the technological achievements demanded by society. Nonetheless shadows still emerge from the unavoidable complexity of current scientific knowledge. Simpler (but false) interpretations of the natural world (e.g. creationism, astrology, etc) may look more appealing than conventional wisdom for people without a scientific background.

In physics, the naive classical determinism of the nineteenth century has been replaced by a set of uncertainties arising from quantum mechanics or chaotic behaviour. More recently, even the essence of the scientific method has become controversial, inasmuch as the anthropic principle is invoked. The pending question of the vacua landscape in string theory has indeed become a nightmare for some buoyant believers in the existence of a (single?) “theory of everything”. In spite of (or perhaps because of) such controversial situation [1, 2], the future of elementary and astro-particle physics, alongside cosmology, definitely looks exciting.

Following the order of the after-dinner talk, we briefly examine in the next section the birth of systematic learning about nature in ancient Greece. As Aristotle put it: “*All men by nature desire to know*”. History of science can teach us many lessons valuable today. If we cannot be sure of where we are going, scientifically speaking, at least let us keep in mind from where we have come.

In the subsequent section, we contemplate the intertwining of the strong interaction and string theories as an example of conceptual entanglement between different fields in physics. New symmetries, new possible spectroscopies corresponding to hidden sectors beyond the Standard Model (SM) were also mentioned during the after-dinner presentation. Finally we stress the relationship between the “large” (astrophysical and cosmological models) and the “small” (nuclear and particle physics), focusing on the detection of (cold) dark matter.

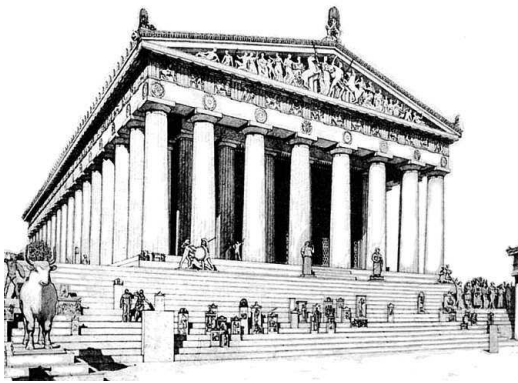


FIGURE 2. A reconstruction of the entrance of the Parthenon. There is considerable discussion about why Athenian culture encouraged philosophy, but a popular theory says that it occurred because Athens had a direct democracy of citizens, albeit excluding women, metics and slaves.

Why (natural) philosophy was born in ancient Greece?

The transition from *Mythos* to *Logos*, the development of arts and the birth of democracy are likely related phenomena in ancient Greek society. Science, the successor to natural philosophy in modern societies, has inherited many of the moral commitments associated with the beginning of rational thought, particularly regarding free-thinking and human rights in open societies [3].

Several circumstances led together to the birth of western philosophy in ancient Greece and not elsewhere: [4]

- Mild weather and plentiful spare time (mainly because of slave labour), permitting sky observations and outdoors (public) life.
- A privileged geographical situation in the Mediterranean sea, favouring the contact with other peoples and cultures, e.g. in Egypt and Babylon.
- Commercial relations. Thinkers like Thales were also men of action, with curious and enterprising spirits. In fact, Athens became a maritime power during the era of Pericles.
- Self-confidence, freedom of speech, and ultimately democracy, with intense participation of citizens in public life.
- Anthropomorphic religion, without holy books and a sacerdotal caste.
- Absence of a central power, in sharp contrast to the Persian empire, contributing to the development of local schools of thought and (self) criticism.
- A flexible and precise (written) language, allowing the expression of abstract concepts, e.g. atom by Democritus.



FIGURE 3. Statue of Alfonso X “the Wise” in Madrid.

At the same time, other circumstances hindered the evolution of natural philosophy into modern science, e.g.

- General neglect of experimentation (with few exceptions like Archimedes or Hero of Alexandria in the Hellenistic period), as manual labour was generally associated with slavery.
- Excessive emphasis by many schools on the moderation (of customs) as a route to happiness, thereby preventing society from technological improvements leading to a better quality of life.
- Dogmatism of schools and diversion of mathematical knowledge towards rather mystic goals, like in the Pythagorean school.

Many of the above remarks are in order today, since intellectual freedom, (self)criticism and dialogue between schools of thinking lie at the heart of scientific progress.

From Dark Ages to Modern Science

According to traditional history, during the Dark Ages (denoting here the entire period between the fall of Rome and the Renaissance) scientific knowledge (and culture) was almost completely swept away in Western Europe. However, current scholars tend to avoid the term altogether for its negative connotations, finding it misleading and inaccurate for some parts of the Middle Ages.

In the Iberian peninsula, the Castilian monarch Alfonso X, nicknamed “the Wise”, was one of these exceptions. From the beginning of his reign, Alfonso employed Jewish, Muslim and Christian scholars at his court. The scientific treatises compiled under Alfonso’s patronage were the work of the celebrated “School of Translators” of Toledo. The *Alfonsine Tables* are particularly well-known, containing diagrams and figures on planetary movements. Because of this, the lunar crater Alphonsus is named after him.

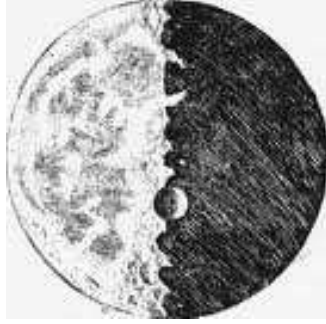


FIGURE 4. Picture of the Moon from Galileo's "Starry Messenger". The small book caused sensation on account of the engravings it contained showing the Moon's uneven surface.

A famous apocryphal quote attributed to Alfonso upon hearing an explanation of the complicated assumptions required in the Ptolemy's view of astronomy was:

If the Lord Almighty had consulted me before embarking upon creation, I should have recommended something simpler.

Indeed, astronomy was called on to play a crucial role in the birth of modern science in the following centuries.

Galileo Galilei published *Sidereus Nuncius* (the "Starry Messenger") in 1610, reporting his observations of the Moon and, particularly, his discovery of four satellites around Jupiter. The lunar observations showed that the surface of the moon was neither smooth nor perfectly spherical, but was covered with craters and mountains. Both discoveries were blows to the Aristotelian world-view which was geocentric and maintained that everything above the Earth was perfect and incorruptible. The door for the return of the old atomistic idea of Democritus and Epicurus had been definitely open.

Nuclear beta decay: a compendium of modern physics

The correct interpretation of X-rays by Röntgen together with the discovery of radioactivity by Becquerel at the end of the twentieth century was an outstanding step forward in modern science. The atom was not to be considered as indivisible, in spite of its etymology!

Below we focus on nuclear beta decay as a good example of the conceptual entanglement of many different issues in the scientific development. First of all, note that the *ad hoc* hypothesis of the existence of an unseen particle postulated by Pauli (called neutrino by Fermi), to preserve energy-momentum conservation in beta decay, represents a landmark in the history of physics of the twentieth century.

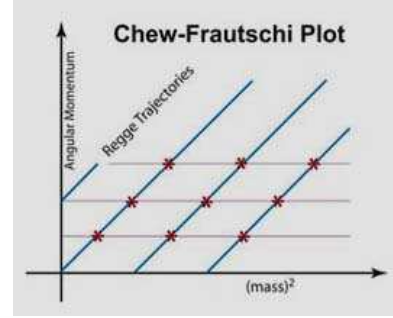


FIGURE 5. Regge trajectories motivating the string description of hadrons.

For example,

- Fermi effective theory brought on the formulation of a pre-gauge theory with a V-A structure, which was later interpreted in terms of the Z^0 and W^\pm mediators.
- The solution to the problem of unitarity violation in the early theory led ultimately to the discovery of non-abelian local gauge invariance (Yang-Mills theories).
- The existence of anti-matter postulated by Dirac is checked in β^+ decay.
- More recently, neutrino oscillations have been the first evidence of physics beyond the SM.
- Neutrino physics is called to play a crucial role in astro-particle physics and cosmology.

FROM HADRONIC STATES TO STRING THEORY

Originally, string theory arose in the late 1960s in an attempt to understand various features of the strong interaction and properties of hadronic states (see Fig.5). The seed of the idea can be traced to the dual resonance model proposed by Gabriele Veneziano. The picture was that, for example, a meson should consist of two quarks tied together by a piece of 'string', acting as a kind of rubber!

In the early 1970s another theory of the strong interaction, Quantum Chromodynamics (QCD), was developed, and proved very successful indeed. QCD is a gauge non-abelian quantum field theory exhibiting some peculiar properties depending on the energy scale: confinement (still to be proved) and asymptotic freedom.

Effective theories, like NRQCD [5] or HQET [6], have become a fruitful approach for different kinematic regimes and mass limits. Let us also mention lattice QCD [7] as a well-established non-perturbative approach formulated on a grid or lattice of points in space and time.

As a result of all this, as well as various technical problems with the primitive string theory approach, string theory fell out of fashion. In the last few decades, however, string theory [8, 9] has turned out to be well suited for an even more ambitious purpose: to become the “theory of everything”! The basic idea is that elementary particles or force carriers should not be described as point-like, but instead viewed as different oscillation modes of a string - the ultimate constituent of nature.

Think of a guitar string. Depending on how the string is plucked and how much tension is in the string, different musical notes will be created. In a similar manner, the elementary particles could be thought of as the excitation modes of elementary strings. Furthermore, the spectrum of string excitations includes a massless particle with two units of spin which can be identified with the graviton, the expected carrier of the quantum gravitational field. Therefore, string theory could unify all four known forces of Nature, including gravitation, the unfulfilled dream of many generations of physicists.

Moreover, higher dimensional objects (branes) were included in the framework by Joseph Polchinski [10], greatly increasing the number of possible background geometries and leading to enormous consequences in later developments of string theory.

If string theory is to be a theory of quantum gravity, then the average size of a string should be somewhere near the Planck length ($\sim 10^{-35}$ m). This means that strings would be, in principle, too small to be directly detected by current or expected particle physics experiments. Cleverer methods of testing the theory than just looking for little strings have to be devised in particle experiments. Nonetheless, other possibilities have to be considered, including TeV stringy effects to be potentially detected at the Large Hadron Collider (LHC).

On the other hand, supersymmetry is required in order to include fermions in string theory (stabilizing the model too). Supersymmetric partners to currently known particles are supposed to be too massive for detection at accelerators till now. However, the LHC could be on the verge of finding evidence for supersymmetry.

An intriguing feature of string theory is that more than three spacial dimensions exist for self-consistency of the theory. This is not really a new idea in physics, with Kaluza’s early work showing that general relativity in five dimensions yields electromagnetism. More generally, string theory provides a theoretical arena in which different compactifications of extra dimensions lead to many different possibilities for physics beyond the SM. Note that extra dimensions can be at reach of the LHC experiments looking for a missing energy signal [11].

Despite all the beautiful and suggestive features (e.g. dualities) of string theory, there is so far one main problem with it: string theorists end up with a landscape of many possible consistent solutions (10^{500} or so), each

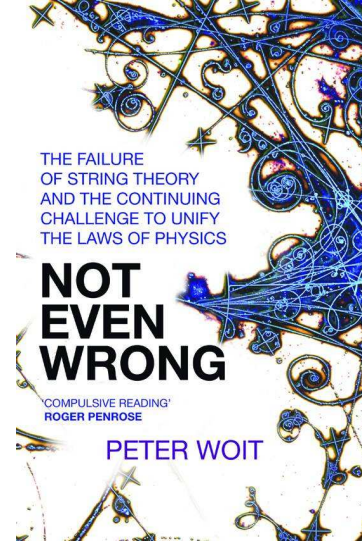


FIGURE 6. The epistemological difficulties of the vacua landscape in string theory has led many physicists to become rather skeptical about it. The title of the book by Peter Woit [13] *Not even wrong*, corresponds to the Pauli’s term for scientifically useless speculative theories (i.e. cannot be falsified).

one with a different vacuum and physical predictions. In all frankness, this should be somewhat discouraging for string theorists ¹.

Strings strike back: Maldacena’s holographic principle

Gerard ’t Hooft’s visionary proposal of the holographic principle [14] was in part an inspiration for Juan Maldacena’s conjecture. Basically, everything that happens in a given volume of space can be represented as taking place (is encoded) on a surface surrounding this volume [15].

Maldacena’s conjecture [16, 17, 18] proposes that a string theory on a certain background spacetime is equivalent to a conformal supersymmetric Yang-Mills theory on a lower dimension (AdS/CFT correspondence). Such a duality implies:

Strongly coupled dynamics \Leftrightarrow Weakly coupled strings and vice versa.

In particular, one may think of QCD as a scale-invariant theory (QCD is almost conformal at momenta much larger than Λ_{QCD}) with a useful correspondence with a certain string theory on a anti-de Sitter spacetime and a closed manifold (like a five dimensional sphere).

¹ Leaving aside the anthropic principle as an arguable way out [12].



FIGURE 7. Ockham’s razor (*entia non sunt multiplicanda praeter necessitatem*) is popularly expressed as “the simplest explanation is more likely the correct one”. The exact meaning of “simplest” must be nuanced however.

Can the dual string theory explain confinement, hadronization, etc?

It should be emphasized that the gauge/string duality has not yet been proved but many non-trivial tests have been carried out. Some physicists do believe that holography is a fundamental property of string theory. Finally notice that recent data from heavy ion processes at RHIC might be interpreted by invoking a dual string theory [19].

NEW SYMMETRIES, NEW WORLDS

Besides the string description, the SM can obviously be extended in many different ways. There are reasonable and motivated scenarios, most of them including supersymmetry since it provides a solution for the Higgs mass problem [20]. Alternative popular scenarios are, e.g., the little Higgs model [21], warped extra dimensions [22] or technicolor [23].

Minimal extensions of the SM can be seen as a theoretical prejudice attached to beauty and elegance of the formalism, also supported so far by many successes in all fields of science. Indeed, one should not forget the scientific virtues usually attributed to a healthy economy of hypotheses (*Ockham’s razor*).

However, let us point out as a caveat that the third generation of quarks and leptons, in the early SM, was in fact not demanded by previous experimental data nor theoretical requirements. In this regard, Einstein warned:

*Everything should be as simple as possible,
but not simpler.*

Among those possible not so much strongly motivated scenarios beyond our present conventional wisdom, new kinds of strong interaction have been considered in particle physics [24, 25]. Actually, the existence of additional gauge groups with matter in the fundamental representations would arise naturally in string theory [26].



FIGURE 8. Portrait of Dora Maar by Picasso. New symmetries (and their breaking) should furnish a guide useful in the search for physics beyond the SM.

For instance, the usual $SU(3) \times SU(2) \times U(1)$ group of the SM can be extended by a new non-abelian group (like in hidden valley models [27]). Higher dimension operators at the TeV scale (induced by a Z' or by a loop of heavy particles carrying charges from both the SM and the new group) should allow interactions between the SM fields and the new particles.

Rather exotic phenomenology would show up at the LHC: high multiplicity events, displaced vertices and missing energy, long range correlations, etc [28, 29].

FROM THE “SMALL” TO THE “LARGE” AND VICE VERSA

Astronomical observations played a leading role in the early development of natural philosophy in ancient Greece (as in previous civilizations) and the scientific revolution by Galileo and Newton (alongside many others). Certainly, “messengers from the sky” (light, cosmic rays, dark matter ...) will still provide us with essential information from/on the Cosmos.

Fundamental questions in physics unite the largest scale (the study of the universe) to the smallest scale (elementary particle physics). In particular, the nature of dark matter [30] directly involves both cosmology and certain extensions of the SM (like supersymmetric models) which furnish candidates (e.g. neutralino, gravitino) for the so-called Weak Interacting Massive Particle (WIMP).

If the Milky Way’s dark matter halo is composed of WIMPs, the WIMP flux on Earth should be about $10^5 \text{ cm}^{-2}\text{s}^{-1}$. Therefore direct detection experiments should be able to detect WIMP elastic scattering off nuclei, providing a signal if backgrounds are low enough.

The WIMP-nucleon (nucleus) cross section (spin-dependent and spin-independent) encodes:

1. Particle physics inputs, including WIMP interaction properties
2. Nuclear properties: hadronic matrix elements describing the quark and gluon content of the nucleon, notably concerning strange quarks.
3. Astrophysics: WIMP velocity distribution, Earth motion.

This is an illustrative example of the multiple fields involved in any claim of observation of dark matter.

CONCLUDING REMARKS

As history teaches us, it is hardly conceivable a steady development of science which leaves aside any area of knowledge. In this paper, we have illustrated this point of view with several examples from both elementary particle and astro-particle physics, as well as cosmology.

Returning to Hilbert's quotation, which entitles this paper, one might complete it by saying:

We must know ... about everything.

In answering these pending big questions about Nature, we should (hopefully) become more "human", that is, wiser in the broad sense of the word (committed in world-wide solidarity, respectful towards the environment...). After all, we should live up to the name of our species: *Homo sapiens*, "knowing man".

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REFERENCES

1. L. Smolin, *The Trouble with physics. The rise of String Theory and the Fall of a Science and what comes next.* Houghton Mifflin, New York, 2006.
2. R. Penrose, *The Road to Reality: A Complete Guide to the Laws of the Universe*, Vintage Books, 2007.
3. Richard Pierre Claude. *Science in the Service of Human Rights*, University of Pennsylvania Press 2002.
4. M.A. Sanchis-Lozano, *Filosofía Griega y Ciencia Moderna: un viaje en el tiempo desde Aristóteles hasta Einstein*, ACDE, Valencia, 2001.
5. G. T. Bodwin, E. Braaten and G. P. Lepage, *Phys. Rev. D* **51**, 1125 (1995) [Erratum-ibid. *D* **55**, 5853 (1997)] [arXiv:hep-ph/9407339].
6. M. Neubert, *Phys. Rept.* **245** (1994) 259 [arXiv:hep-ph/9306320].
7. C. Gatttringer and C. B. Lang, *Quantum Chromodynamics on the Lattice*, Springer 2010.
8. B. Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory*, Vintage Series, Random House Inc, 2000.
9. K. Becker, M. Becker and J.H. Schwarz, *String Theory and M-Theory*, Cambridge University Press, Cambridge, 2007.
10. J. Polchinski, "Lectures on D-branes," arXiv:hep-th/9611050.
11. G. Aad *et al.* [The ATLAS Collaboration], "Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics," arXiv:0901.0512 [hep-ex].
12. L. Susskind, "The anthropic landscape of string theory," arXiv:hep-th/0302219.
13. Peter Woit, *Not Even Wrong: The Failure of String Theory & the Continuing Challenge to Unify the Laws of Physics.*, Basic Books, 2006.
14. C. R. Stephens, G. 't Hooft and B. F. Whiting, *Class. Quant. Grav.* **11**, 621 (1994) [arXiv:gr-qc/9310006].
15. L. Susskind, *J. Math. Phys.* **36**, 6377 (1995) [arXiv:hep-th/9409089].
16. J. M. Maldacena, *Adv. Theor. Math. Phys.* **2**, 231 (1998) [arXiv:hep-th/9711200].
17. S. S. Gubser, I. R. Klebanov and A. M. Polyakov, *Phys. Lett. B* **428**, 105 (1998) [arXiv:hep-th/9802109].
18. E. Witten, *Adv. Theor. Math. Phys.* **2**, 253 (1998) [arXiv:hep-th/9802150].
19. W. A. Horowitz, "Probing the Frontiers of QCD," arXiv:1011.4316 [nucl-th].
20. M. Drees, "An Introduction to supersymmetry," arXiv:hep-ph/9611409.
21. M. Schmaltz and D. Tucker-Smith, *Ann. Rev. Nucl. Part. Sci.* **55**, 229 (2005) [arXiv:hep-ph/0502182].
22. L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83**, 3370 (1999) [arXiv:hep-ph/9905221].
23. E. Farhi and L. Susskind, *Phys. Rept.* **74**, 277 (1981).
24. L. B. Okun, *Nucl. Phys. B* **173**, 1 (1980).
25. J. Kang and M. A. Luty, *JHEP* **0911**, 065 (2009) [arXiv:0805.4642 [hep-ph]].
26. N. Arkani-Hamed, S. Dimopoulos and S. Kachru, "Predictive landscapes and new physics at a TeV," arXiv:hep-th/0501082.
27. M. J. Strassler and K. M. Zurek, *Phys. Lett. B* **651**, 374 (2007) [arXiv:hep-ph/0604261].
28. T. Han, Z. Si, K. M. Zurek and M. J. Strassler, *JHEP* **0807**, 008 (2008) [arXiv:0712.2041 [hep-ph]].
29. M. A. Sanchis-Lozano, *Int. J. Mod. Phys. A* **24**, 4529 (2009) [arXiv:0812.2397 [hep-ph]].
30. G. Bertone, D. Hooper and J. Silk, *Phys. Rept.* **405**, 279 (2005) [arXiv:hep-ph/0404175].